AD ________________

MIPR NO: 95MM5582

TITLE: Relationship Between Neck Strength, Anthropometric Parameters, and Gender with Head Motion under Impact Acceleration

PRINCIPAL INVESTIGATOR(S): CAPT Charles E. Morris

CONTRACTING ORGANIZATION: Armstrong Laboratory
Wright Patterson AFB, OH 45433

REPORT DATE: April 1996

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Frederick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release; distribution unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1996

3. REPORT TYPE AND DATES COVERED
Final (23 Jan 95 - 30 Sep 95)

4. TITLE AND SUBTITLE
Relationship Between Neck Strength, Anthropometric Parameters, and Gender with Head Motion Under Impact Acceleration

5. FUNDING NUMBERS
95MM5582

6. AUTHOR(S)
CAPT Charles E. Morris

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Wright Patterson AFB, OH 45433

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick
Frederick, Maryland 21702-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)* With the opening of the fighter cockpit to women, it is imperative to expand the current database of responses of females to high impact acceleration environments. Since women tend to have less upper-body strength than men, it was hypothesized that they may not be able to brace their heads as effectively against the loads which occur during impact and escape.

The objective of the current experimental effort was to examine the ability of subjects of both sexes to brace against an impact acceleration of -6.5 Gx or -4.0 Gy, and to attempt to identify a correlation between such ability, static strength measurements, anthropometric measurements, or any combination thereof.

The isometric strength measurements correlated well with anthropomorphic measurement, but none of these proved useful in predicting the head displacement. However, a strong relationship was found for both sexes between neck force exerted just before impact and head motion in the Gx study. A weaker correlation was noted for the Gy impacts for males.

It is therefore useful to estimate female resistance to impact by measuring static neck strength. In order to predict male impact resistance, the neck strength must be measured under impact conditions where the subject is highly motivated.

14. SUBJECT TERMS
Defense Women's Health Research Program
Volunteers
Neck Strength
Anthropometric Data
Head Motion
Impact Acceleration
Gender Differences

15. NUMBER OF PAGES
20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements*.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	Contract	PR	Project
G	Grant	TA	Task
PE	Program Element	WU	Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

- DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
- DOE - See authorities.
- NASA - See Handbook NHB 2200.2.
- NTIS - Leave blank.

Block 12b. Distribution Code.

- DOD - Leave blank.
- DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
- NASA - Leave blank.
- NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

FOREWORD

Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the U.S. Army.

______ Where copyrighted material is quoted, permission has been obtained to use such material.

______ Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

✓ Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

______ In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Animal Resources, National Research Council (NIH Publication No. 86-23, Revised 1985).

✓ For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 32 CFR 219 and Subparts B, C, and D.

______ In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institutes of Health.

______ In the conduct of research utilizing recombinant DNA, the investigator(s) adhered to the NIH Guidelines for Research Involving Recombinant DNA Molecules.

______ In the conduct of research involving hazardous organisms, the investigator(s) adhered to the CDC-NIH Guide for Biosafety in Microbiological and Biomedical Laboratories.

Prinicpal Investigator's Signature

[illegible] MAR 1998

Date

TABLE OF CONTENTS

INTRODUCTION

With the opening of the fighter cockpit to women, it is imperative to expand the current database of responses of females to high impact acceleration environments. It was hypothesized that since women tend to have less upper-body strength than men, they may not be able to brace their heads as effectively against the loads which occur during impact and escape. This may be exacerbated by the changing center of gravity of helmets due to technological advances (e.g. night vision, head-up displays, etc).

The objective of the current experimental effort was to examine the ability of subjects of both sexes to brace against an impact acceleration in the X or Y axes, and to attempt to identify a correlation between such ability, static strength measurements, anthropometric measurements, or any combination thereof.

The potential for injury to the pilot is increased if adequate data is not available for design of restraint and impact protection systems. It is currently unknown if women are more likely to suffer injuries to the head and neck as a result of ejection impacts, although in a 1988 study of automobile accidents(1), women were shown to be approximately 25% more likely to be fatally injured. A study by Foret-Bruno et al.(2) also demonstrates a 20% increased thoracic injury risk in females in restrained automobile crashes.

It seems reasonable, then, to assume that female pilots might be significantly more likely to be injured by an impact such as that sustained during ejection. One such mechanism of injury is hyperflexion of the head, which is especially relevant when considering the proposed use of steerable ejection seats. Forward and lateral deflection of the head under impact is readily measured at levels which will not cause injury to the test subject. Thus this parameter was selected for experimental measurement.

The critical issues addressed by this test program and subsequent analytical efforts using the collected data are summarized as follows:

a. How well does neck strength correlate to head motion under impact?

b. Do anthropometric parameters correlate to head motion under impact?

c. Does gender correlate with head motion under impact?

The specific parameters measured were:

a. Neck diameter and neck length from right mastoid process to C_7 spinous process.

b. Passive range of motion (ROM) of the neck (e.g., rotation, side-to-side) (description below).

c. Maximum strength of the neck in lateral and front-to-back direction and duration of maximum voluntary contraction (MVC).

d. Deflection of the head during an impact acceleration in the -Gx and +Gy directions.

METHODS

Thirty-four subjects (including 16 females) were initially selected for participation. These subjects were volunteer members of the Armstrong Laboratory Impact Acceleration Panel. They receive hazardous duty pay for their participation and undergo a minimum of one run per month for training.

All subjects were measured for anthropomorphic characteristics. They were requested to exert force against pads fixed to load cells in order to quantitate their neck strengths.

In the second phase of the project, the same subjects underwent horizontal impact exposures in which the motion of the subject's head was recorded via infrared sensors and accelerometers. The collected data was then analyzed to determine whether there was a correlation between gender and ability to resist an impact, or between anthropomorphic measurements and resistance.

Static Test Phase

Range of motion measurements were taken of the neck (side to side and rotation). These measurements were performed in all cases by Dr. Stephen Popper, DO, to eliminate interoperator variability. Each subject lay on a portable manipulation table in the supine position, and was directed to remain relaxed. The lateral range of motion was determined by grasping the subject's head and deflecting it laterally (without allowing rotation) to a point at which resistance was found. The deflection was then read directly from a scale fixed to the table. The rotation measurement was obtained in a similar manner, using an inclinometer fastened to Dr. Popper's hand (which remained in a fixed position relative to the subject's head during rotation).

The subjects were then seated in an aluminum chair (padded with 1/8 inch neoprene sheeting for comfort) which was bolted to a rigid framework. A framework bearing adjustable pads connected to load cells was lowered over the subject's head so that the force exerted with the neck muscles could be measured.

(Figure 1 here)

A maximal effort using only the muscles of the neck was recorded in the X and Y directions, which was sustained for approximately 10 seconds or until a 30% decrease from maximum occurred. A maximal short-duration (i.e. 2 second) effort, allowing use of the upper torso and extremities, was then recorded using four instrumentation amplifiers (model 8655; Pacific Instruments, Concord CA) driving a 12-bit analog-to-digital converter card (model "Lab PC+"; National Instruments, Austin TX). A PC with appropriate software written in C++ under National Instruments' LabWindows/CVI was then used to digitize the data in real-time and collect it onto disk (along with manual entry of the anthropometric data described above).

Dynamic Test Phase

In the dynamic measurement phase, the same volunteers were exposed to impact accelerations in the X and Y axes. The acceleration and displacement of the sled and subject were measured.

All tests were conducted on the Horizontal Impulse Acceleration (HIA) facility. This facility consists of a Bendix 24-inch "Hyge" pneumatic accelerator driving a 2000 lb sled down a 240 ft track. The unit is capable of over 100 G acceleration, and has a maximum stroke of 8.4 feet. Pulse widths up to approximately 265 ms may be produced, and the shape of the acceleration pulse is determined by fixed metering pins within the pneumatic cylinder of the accelerator. A complete description of the facility is available (3).

One of two manikins was used during this test program on the initial test run of each testing day. The first type is a 95th percentile anthropomorphic manikin referred to as the GARD. The second type is the 95th percentile prototype Advanced Dynamic Anthropomorphic Manikin (ADAM). Manikins were dressed in a HGU-55/P helmet and cutoff long underwear.

The experimental test fixture was the 40-G seat mounted on the IA sled and oriented to provide a -Gx or +Gy acceleration vector. The seat incorporates the geometry of MIL-STD-1472B modified for a zero degree seat back angle and with the seat back plane perpendicular to the seat pan plane. The subjects were restrained using a PCU-15/P harness, two shoulder straps, and an ACES II lap belt. The lap belts were pretensioned to 20 +/- 5 lb at each anchor point. The shoulder straps were also preloaded to 20 +/- 5 lb.

The impact accelerations were -6.5 Gx (eyeballs-out) or -4.0 Gy (eyeballs-right) with a pulse duration fixed at 200 msec. These levels are well below the approved limits of the AL Generic Impact Acceleration Protocol(4), but still result in easily measurable head motion.

(Figure 2 here)

(Figure 3 here)

Motion analysis data was collected prior to the acceleration of the sled as well as during the impact event. The motion analysis data was recorded using the Selspot system (infrared LED's affixed to the subject and IR cameras mounted on the test fixture at oblique and right angles to the subject). Data was collected at 500 samples/sec. The motion analysis data consists of displacement-time histories of targets mounted on the test seat, impact sled, and test subjects. The positions of the targets mounted on the test subjects were as follows: top of helmet; temple (approximately 2 cm dorsal to the supraorbital ridge); mouth (mounted to bite bar); C7 vertebra; shoulder; chest pack.

Head and chest accelerations and displacements were measured with a transducer pack composed of linear accelerometers and an infrared motion target. The head triaxial accelerometer was fixed to a hard plastic mouthpiece with silicone rubber biting surfaces fabricated individually for each subject. The chest triaxial accelerometer array was fastened firmly at the subject's sternum with a circumferential Velcro chest strap. The accelerations and displacements at C7 were also measured with a transducer pack of linear accelerometers; this pack was secured to the skin around C7 with a special adhesive tape. The infrared motion target was not used at C7 since it could not be seen by the sled-mounted cameras (blocked by the subject's neck and helmet).

The transducer signals at the IA are handled by the on-board Data Acquisition System (DAS). Signal conditioning, filtering,

amplification, and digitizing (at a rate of 1000 samples/sec) take place on-board the test fixture. The digitized data is transmitted to the impact facility computer room for storage on hard disk and optical media and is post-processed by the VAX computer system. This post-processed data was then combined with the data file from the PC into a file format suitable for input to Statistica, a data analysis package available from StatSoft.

RESULTS

Nineteen subjects (7 females) participated in both the static and -Gx impact phases of the study; 14 males and 8 females participated in both the static and -Gy impact phases. The remainder of the subjects either left the panel before completing both phases, or were unavailable for participation during the available time for anthropometric measurements or sled runs. Several of the smaller female subjects withdrew from the study after experiencing the -6.5 Gy impact; one left after witnessing a -6.5 Gy run, and one declined further impacts after an uneventful -4.0 Gx training run. There were no clinically significant injuries. There were also unexpected complaints of neck soreness from two of the larger male subjects (resulting in the withdrawal of one). In order to forestall further withdrawals, Y impact testing was restarted at 4.0 G. This was well tolerated by the remaining subjects, while still providing sufficient head motion.

Statistical analysis and graphing of the experimental data was performed using Statistica for Windows version 5.0. A correlation matrix was created from all variables (the anthropometric parameters, measured accelerations, and displacements). Surprisingly, no correlation was found between static neck strength and head deflection under impact ($r \sim= 0.04$), which had been expected to exhibit a strong negative correlation; that is, strength should have been inversely proportional to head displacement. However, when the data was grouped by gender, the females were found to have a high correlation ($r = -0.80$), and the males were poorly correlated ($r = 0.11$).

(Figure 4 here)

It was then observed that subjects would be expected to have a displacement for a given head acceleration which was proportional to the length of the neck. A new column (corrected mouth deflection) was obtained by dividing the resultant mouth deflection (computed from the square root of the sum of squares of X, Y and Z displacement) by the neck length as measured from the C7 vertebra to the mastoid process. The units are dimensionless, as both the mouth deflection data and the neck length are in centimeters. (In the discussion below, this value is referred to as the corrected head deflection, since the position of the mouth sensor with respect to the head is fixed by the bite bar).

Upon closer examination, it was discovered that the actual force exerted by the subjects when undergoing impact was not well correlated with the force exerted under static conditions. When the headrest force was used as the independent variable, strong correlations were noted with corrected head motion ($r = -0.88$ females, -0.93 males).

DISCUSSION

The height and weight of the subjects are correlated with their neck strengths, and, as expected, the females tend to be smaller and

exert less neck force. Not surprisingly, the heavier subjects with thicker necks in general were able to exert the most force.

Analysis of the data did not suggest a strong correlation between subject strength (as measured on the static assembly) and head deflection. Neither body weight nor neck dimensions correlated well with the resultant head deflection. However, in regard to static strength versus head deflection, the male data had a weak correlation ($r = 0.47$), and the female data was uncorrelated ($r = -0.06$).

(Figure 5 here)

Gender was not found to be a predicting factor. In the -Gx experiments, while the mean corrected head deflection was similar for males and females (0.84 vs. 0.98), the males exhibited a considerably larger standard deviation (0.47 vs. 0.23).

(Figure 6 here)

The +Gy runs showed a lower value for mean head deflection (males = 1.53, females = 2.08) but with similar variability (SD = 0.60 vs. 0.57).

However, when the actual headrest force exerted just before impact was used as the independent variable, rather than the static test strength, a strong correlation was found with mouth deflection under Gx impact for both males and females.

(Figure 7 here)

The correlations were weaker for the Gy impact tests ($r = -0.70$ females, -0.33 males) but exhibited a similar pattern.

(Figure 8 here)

There is a poor association between static strength and "motivated" strength (i.e. at the instant before impact); the male data is essentially uncorrelated, and the female data is only $r = 0.24$.

(Figure 9 here)

This is significant because it does confirm the hypothesis that stronger subjects tend to deflect less under Gx impact, but it also illustrates a previously unforeseen problem, namely, that in non-stressful conditions the level of motivation (to protect oneself against the impact) strongly influences the force exerted.

In the -Gy impacts, experience with side-impact was probably a confounding factor, as relatively inexperienced subjects appeared to exhibit large deflections even at the modest level of -4.0 Gy which was used.

In conclusion, resistance to impact may be predicted with reasonable accuracy for female subjects by measuring static neck strength. It is currently unclear why the male subjects exhibited so much variability in their level of motivation (the ratio of dynamic to static neck strength). In order to predict male impact resistance, the neck strength apparently must be measured under impact conditions where the subject is highly motivated.

ACKNOWLEDGEMENTS

The extensive assistance of SSgt Jeffrey Briggs in coordinating the scheduling of subjects is hereby acknowledged.

The opinions and conclusions in this paper are those of the authors and do not necessarily represent the views of the U.S. Air Force.

REFERENCES

1. Evans L, "Traffic Safety and the Driver", 1991 New York: Van Nostrand Reinhold, 1991

2. Foret-Bruno JY et al. "Females More Vulnerable than Males in Road Accidents", Proceedings of the XXIII FISITA Congress, Torina, Italy, Vol. 1, pp.941-7; May 1990.

3. Shaffer JT, "The Impulse Accelerator: An Impact Sled Facility for Human Research and Safety Systems Testing", Technical Report AMRL-TR-76-8 (Wright-Patterson AFB, OH: Aug. 1976).

4. "Generic Impact Acceleration Protocol, 1995-97", Armstrong Laboratory Protocol #84-01 (Wright-Patterson AFB, OH).

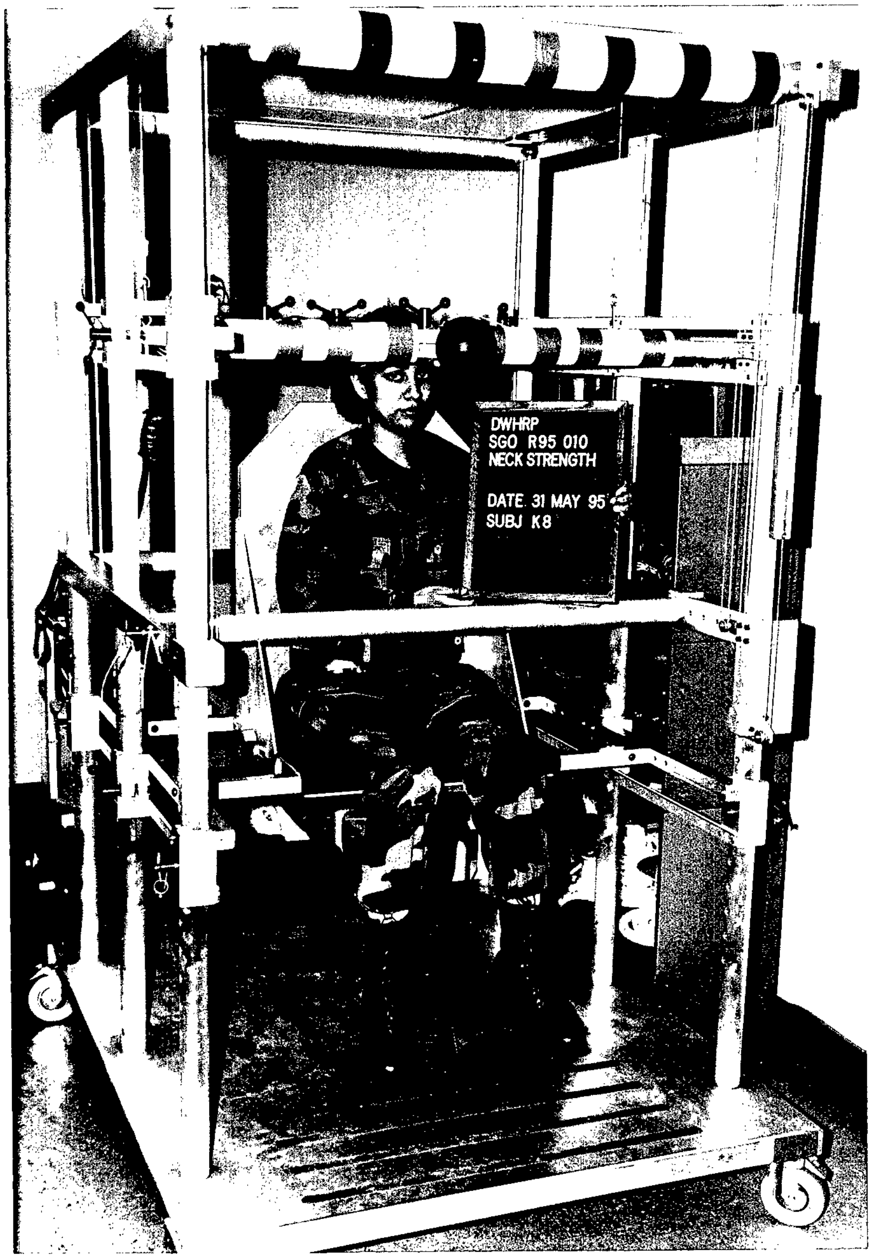

Figure 1. Static neck strength fixture

Figure 2. Subject on Horizontal Impact Accelerator (configured for -Gx impact)

Figure 3. Subject on Horizontal Impact Accelerator (configured for -Gy impact)

Figure 4.

Fig. 4. Mean corrected mouth deflection vs. backward push (Gx=-6.5)
(Correlates poorly for males but reasonably well for females).

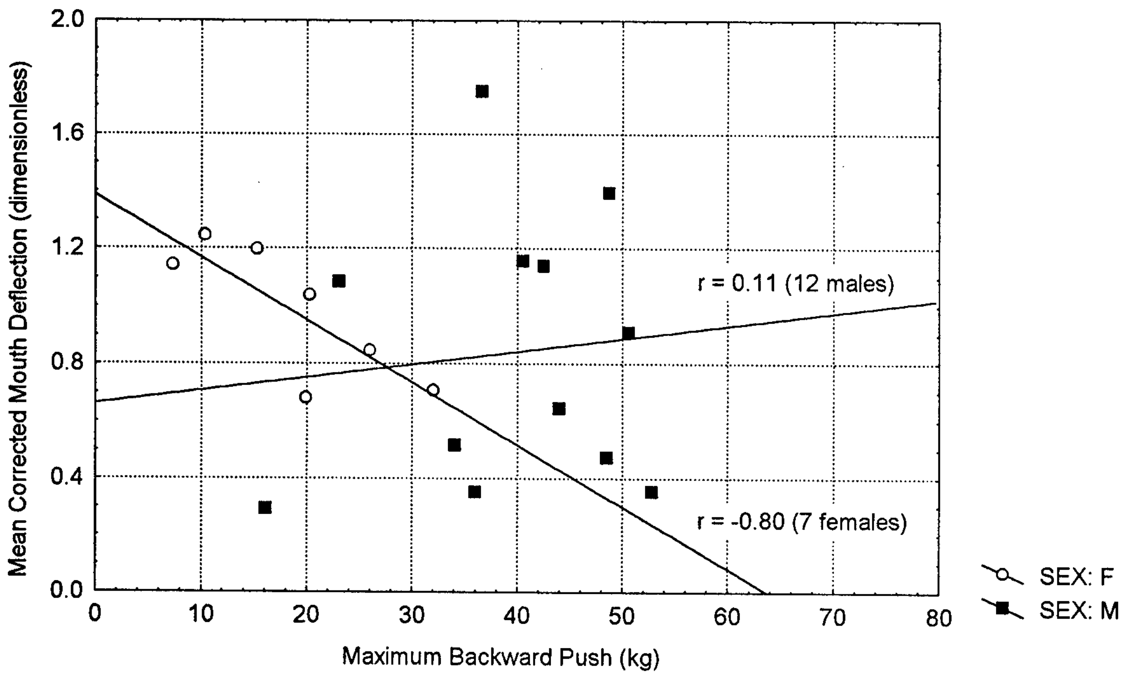

Figure 5.

Fig. 5. Mean corrected mouth deflection vs. body weight (Gx=-6.5)
(Body weight is not a reliable indicator of head deflection magnitude).

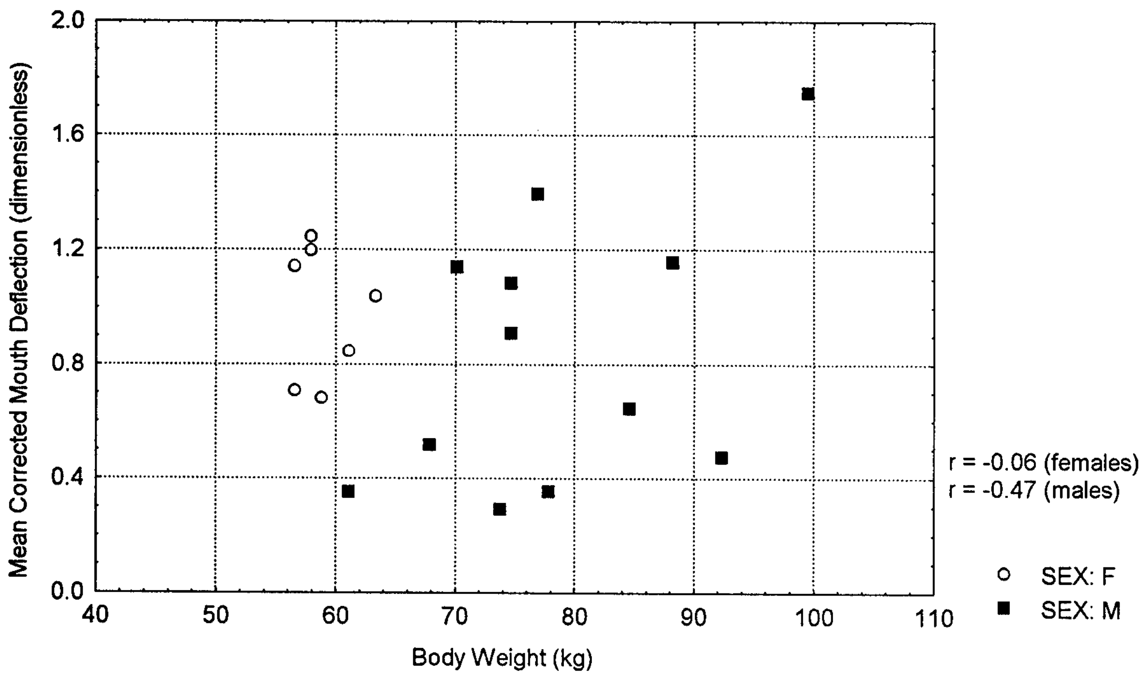

Figure 6.

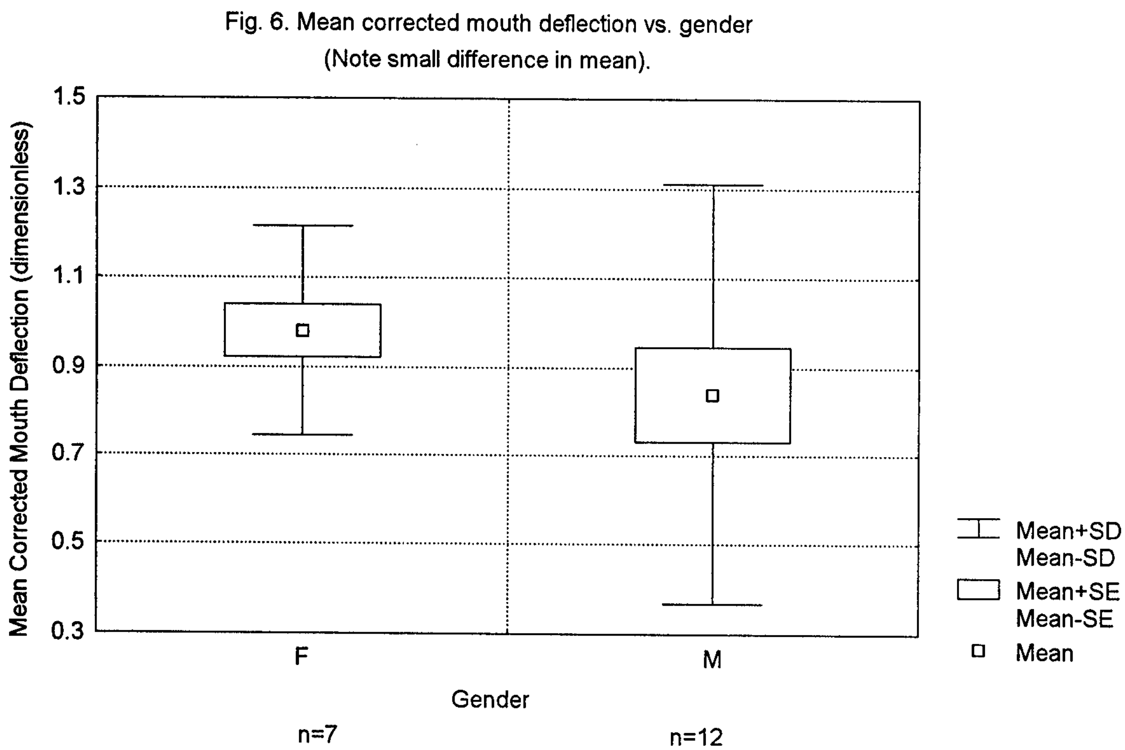

Fig. 6. Mean corrected mouth deflection vs. gender
(Note small difference in mean).
Mean Corrected Mouth Deflection (dimensionless)
1.5
1.3
1.1
0.9
0.7
0.5
0.3
F
M
Gender
n=7
n=12
Mean+SD
Mean-SD
Mean+SE
Mean-SE
Mean

Figure 7.

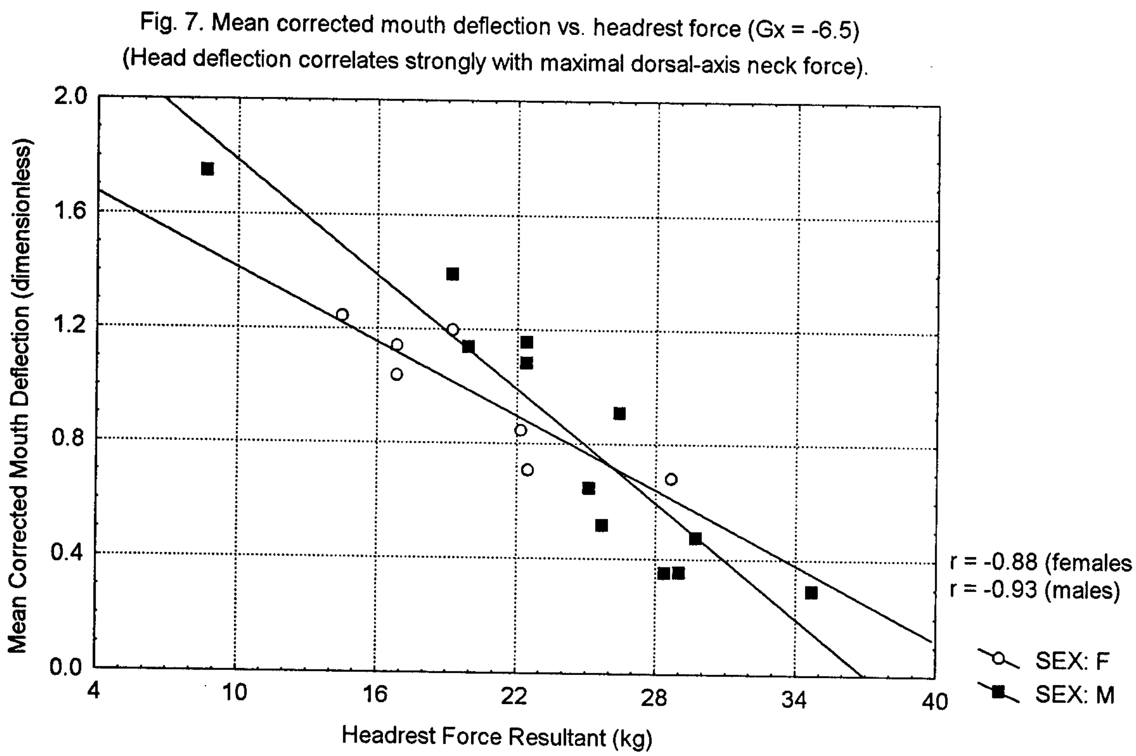
Fig. 7. Mean corrected mouth deflection vs. headrest force (Gx = -6.5)
(Head deflection correlates strongly with maximal dorsal-axis neck force).
Mean Corrected Mouth Deflection (dimensionless)
2.0
1.6
1.2
0.8
0.4
0.0
4
10
16
22
28
34
40
Headrest Force Resultant (kg)
r = -0.88 (females
r = -0.93 (males)
SEX: F
SEX: M

Figure 8.

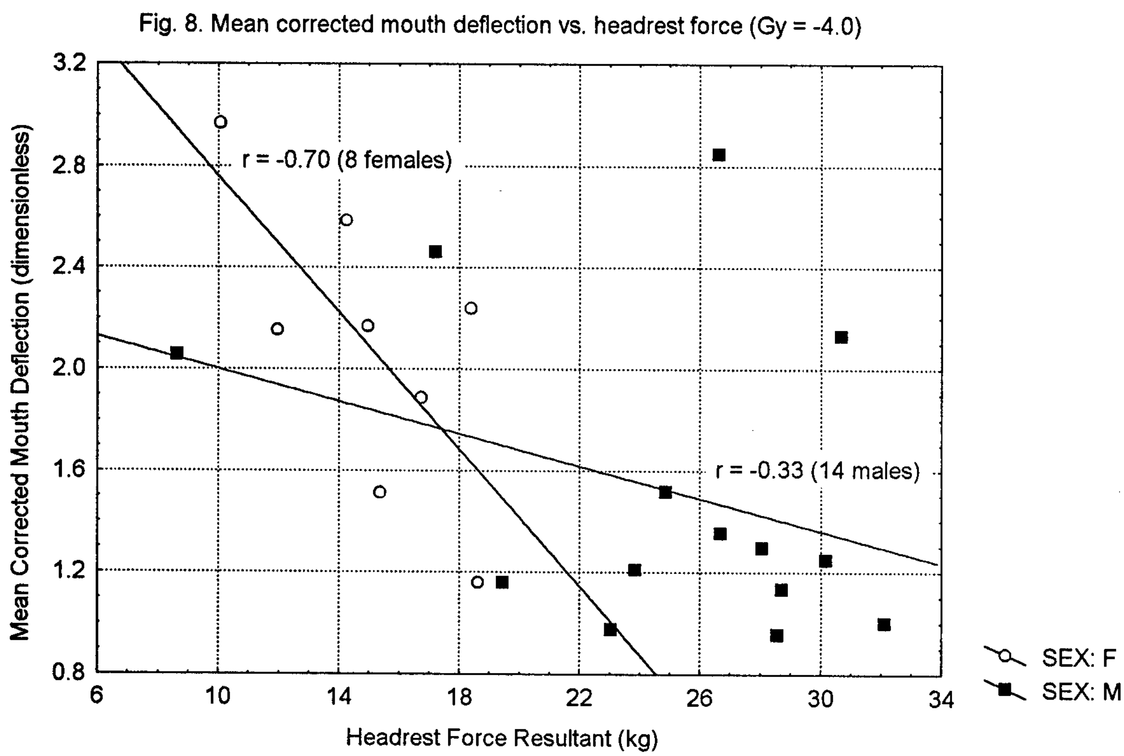

Fig. 8. Mean corrected mouth deflection vs. headrest force (Gy = -4.0)
r = -0.70 (8 females)
r = -0.33 (14 males)
Mean Corrected Mouth Deflection (dimensionless)
Headrest Force Resultant (kg)
3.2
2.8
2.4
2.0
1.6
1.2
0.8
6
10
14
18
22
26
30
34
SEX: F
SEX: M

Figure 9.

Fig. 9. Motivation Factor (Gx = -6.5)
(Headrest resultant force at impact vs. static strength)